Analysis of the Effect of Laser Bandwidth on Imaging of Memory Patterns

Nakgeuon Seong[a], Insung Kim[b], Dongwoo Kang[b], Sang-Ho Lee[b], Jinphil Choi[b]
[a]Cymer Inc. 17075 Thornmint Ct., San Diego, CA 92127 USA
[b]Samsung Electronics Co, San #16 Banwol-Dong, Hwasung-City, Gyeonggi-DO, Korea

ABSTRACT

Tighter CD control requirements of the smaller devices in modern semiconductor products demand control of all potential sources of change in imaging characteristics. Bandwidth of ArF lasers is known to be one of the important parameters to be controlled to improve CD control of wafers. CD changes of Device Critical Patterns for memory products, for example spacing of DRAM isolation patterns, due to laser bandwidth changes were investigated through simulations. The purpose of the simulation study was to find out if there are optimum combinations of layout and illumination setting, if variations can be compensated by illumination adjustments and if the bandwidth performance of the laser meets requirements. The simulations were carried out using Cymer proprietary methods for high accuracy using improved laser spectrum sampling techniques[1]. Different CD behavior was observed for different combinations of pattern layout, illumination and bandwidth. Preferred illumination settings were found which suppress CD changes caused by bandwidth variation, especially for diffusion layer of DRAM layouts. Adjustment of illumination settings was demonstrated to cancel out CD shifts due to bandwidth change for the diffusion layer case. For all example cases, which demonstrated typical DRAM product conditions, simulation verified that the amount of CD shift can be controlled within allowed tolerances if Cymer's ABS technology was used for bandwidth control.

Keywords: light source, laser bandwidth, memory patterns, optimization of illumination, ABS

1. INTRODUCTION

There have been multiple studies discussing laser bandwidth impact on OPE curves and Iso-Dense Bias (IDB)[2]-[6], However, most studies focused on 1D patterns and few studies have reported CD behavior of highly repetitive 2D patterns, like memory cell layouts with strong Off Axis Illumination (OAI) . In this paper, bandwidth sensitivities of DRAM patterns, diffusion and gate layers which require tight CD control since those layers form transistors, were examined. Cell layout of diffusion layer of DRAM has very different periodicities orthogonally and very tight requirements of space CDs. Due to the high regularity of memory patterns, use of customized illumination with strong OAI is popular. Therefore the relationship between illumination shapes and bandwidth sensitivities were also investigated.

1.1 Layouts and simulations set up

Two types of cells, one with traditional 8F2 layout style and the other with 6F2 layout style, were investigated. The layouts are generated from simple approximation of typical DRAM layouts based on layout examples from published reports[7]. Two different layout styles generate the different layouts of diffusion layer as illustrated at Figure 1, but a common layout is used for gate layer. Two illumination settings were used for each diffusion layout, one has a higher level of customization including illuminator angle optimization and the other used just annular illumination with optimized sigma center for minimum pitch of the layouts. Only annular illumination was used for gate layer since multiple pitches and sizes requiring tight CD control can exist in real layout of the layer.

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Layout	Cell style	Illumination type	Pattern size
DRAM diffusion	2 (8F2, 6F2)	2 (customized quad, annular)	4 (half pitch:71nm, 62nm, 49nm, 43nm) (k1 0.34 & k1 0.31 for 0.93NA & 1.35NA)
DRAM gate	1 (same for both)	1 (annular)	4 (same as above)

Table 1. Simulation split conditions

Two k1 factor cases are also chosen to demonstrate a typical DRAM manufacturing case (k1=0.34) and an aggressive case (k1=0.3). For the isolated two lines of the gate layer, both patterns with Sub-Resolution Assist Feature (SRAF) and without SRAF were investigated to determine the benefits of SRAF use for non-dense patterns.

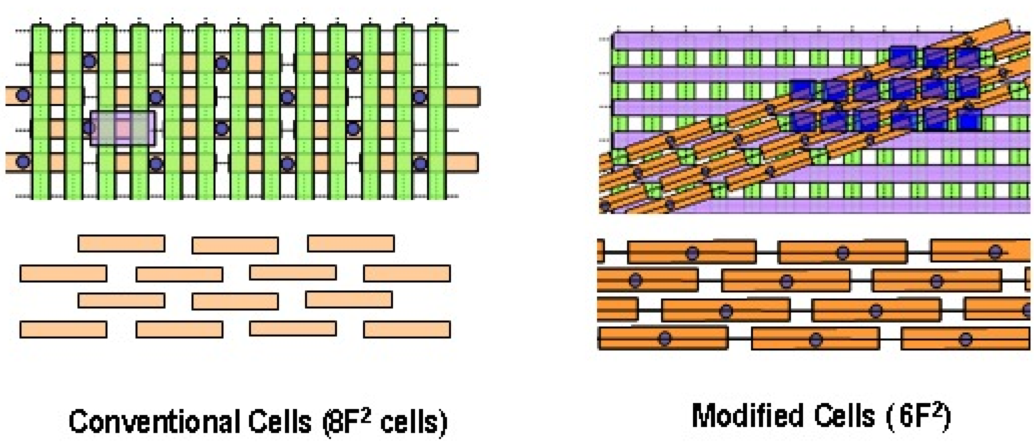

Figure 1. Diffusion layouts by cell types. 6F2 cell layout is rotated for easier simulation set up. Illuminator shape was corrected for the rotation during simulations.

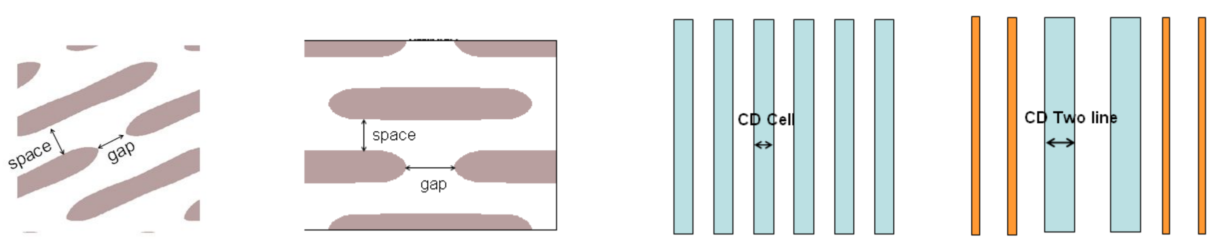

Figure 2. CD measurement points, which are selected based on importance of the size for DRAM device

CDs were monitored at two critical spaces inside the cell for the diffusion layer, and at dense line and isolated two lines for gate layer. Control targets of all CDs were set to be less than 5% of nominal.

2. SIMULATION RESULTS AND ANALYSIS

Two diffusion layout styles, 6F2 and 8F2, and gate layer case are separately analyzed. Potential use of illumination condition adjustment to correct bandwidth induced CD shift was investigated for the diffusion layer case. Dependence on illumination settings and k1 factor were investigated. CDSDPM, CD Shift per Deci-Pico Meter bandwidth (E95) change (nm/0.1pm), which is the CD sensitivity to total bandwidth change range when bandwidth control is used, was evaluated.

2.1 Dependence on illumination and k1 factor – 8F2 Diffusion layer

Both custom illumination and annular illumination cases showed the same CD shift direction of Y-space to bandwidth changes, CDSDPM became steeper with lower k1 imaging, from 0.3 to 0.5, and it was difficult to judge which illumination case had lower slope to bandwidth changes (Figure 3). For X-gap CD, the annular illumination case showed about half the CDSDPM compared to the custom illumination case, and 0.3 k1 case showed twice as large CDSDPM compared to the 0.34 k1 case, for both illumination settings. Therefore CDSDPM for custom illumination with 0.3 k1 is over four times larger than CDSDPM for annular illumination with 0.34 k1. For example CDSDPM is -0.4 for annular illumination with 0.93 NA and 0.34 k1 and -2 for custom illumination with 0.93NA and 0.3 k1 (Figure 4).

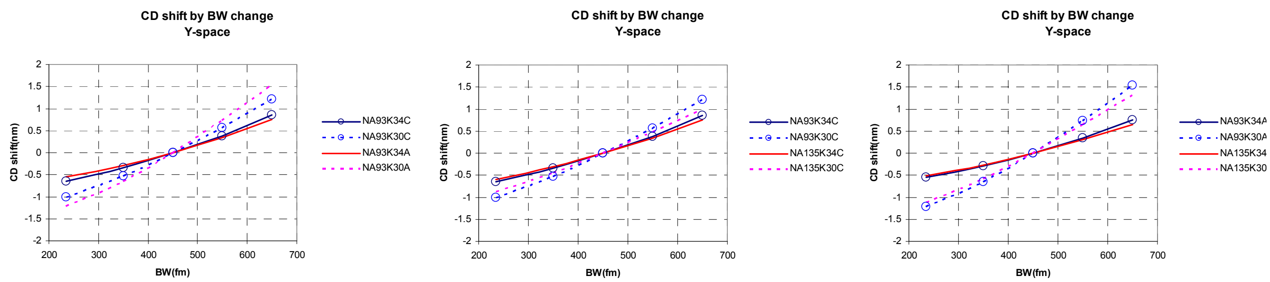

Figure 3. Y-space CD shift due to bandwidth change (E95) for 8F2 cell design. Left graph shows dependenc of CDSDPM on illumination condition and k1 at the same NA. Middle and right show dependence of k1 and NA at the same illumination condition.

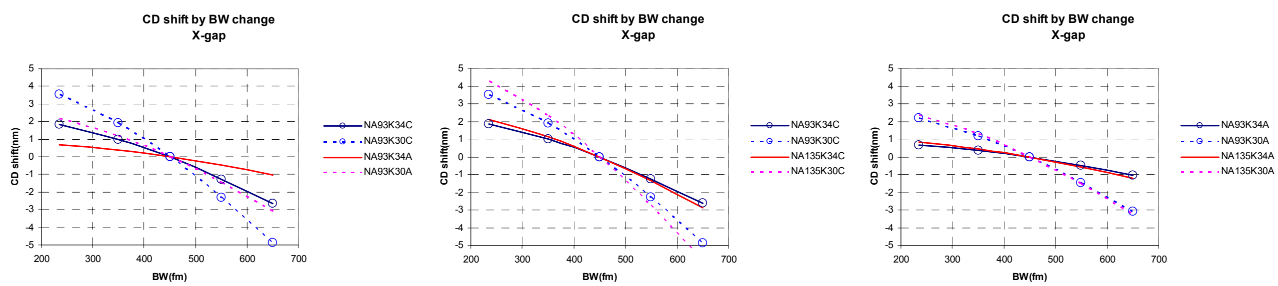

Figure 4. X-gap CD shift due to bandwidth change (E95) for 8F2 cell design. Left graph shows dependenceof CDSDPM on illumination condition and k1 at the same NA. Middle and right show dependence of k1 and NA at the same illumination condition.

If a real production environment is considered, the difference between Y space shift and gap shift needs to be considered. If the CD shifts are in the same direction, both Y-space and X-gap can be corrected by dose adjustment. However the CD shift direction of Y-space is opposite of X-gap, so a dose correction approach doesn't help at all. If this method is used to provide better control of one CD, for example Y-space CD in the Figure 5 case, the CD error from the other will have added, which makes worse CD errors of the patterns in the end (Figure 5.), for example CDSDPM reaches -2.44 for custom illumination with 1.35NA and 0.3 k1.

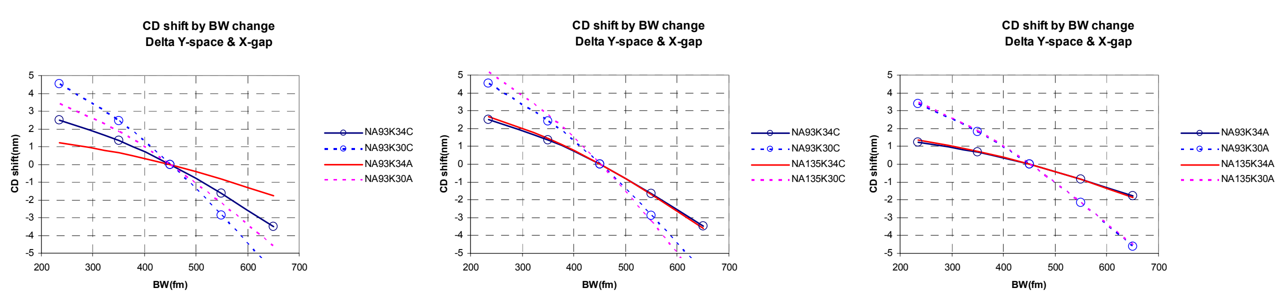

Figure 5. Practical CD delta due to bandwidth change (E95) for 8F2 cell design. Left graph shows dependence of CDSDPM on illumination condition and k1 at the same NA. Middle and right show dependence on k1 and NA at the same illumination condition.

2.2 Dependence on illumination and k1 factor – 6F2 Diffusion layer

For the 6F2 case, CDSDPM of the Y-space was much more stable and smaller for custom illumination compared to annular illumination and for k1 changes (Figure 6.) For the annular illumination case, CDSDPM becomes larger as the k1 factor gets smaller, from 0.4 to 0.7. However, CDSDPM remained below 0.23 with k1 and NA change, with little dependence for custom illumination . Interestingly the CD change direction of the Y-space with custom illumination was opposite from annular illumination . However the amount of CDSDPM of X-gap CD with custom illumination was not better than annular illumination (Figure 7.) Actually, custom illumination had larger CDSDPM at 0.3 k1 compared to annular illumination, about 10 percent worse. CDSDPM of X-gap CD for both illumination cases showed strong dependence on k1 factor but not on NA.

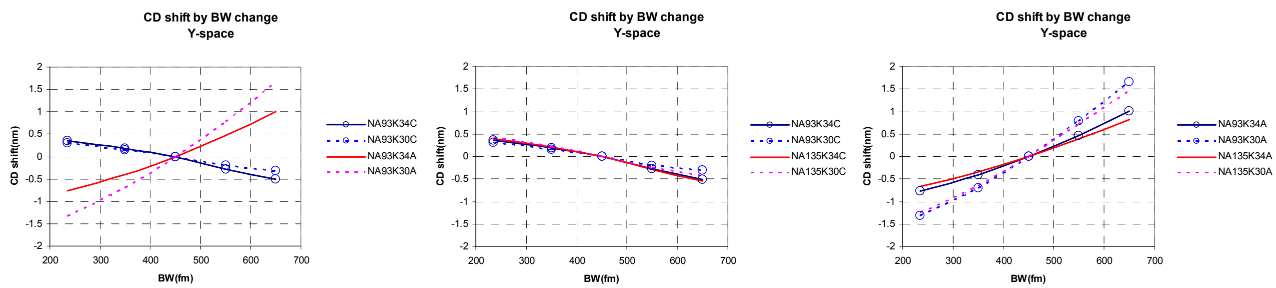

Figure 6. Y-space CD shift due to bandwidth change (E95) for 6F2 cell design. Left graph shows the dependence of CDSDPM on illumination condition and k1 at the same NA. Middle and right show dependence on k1 and NA at the same illumination condition.

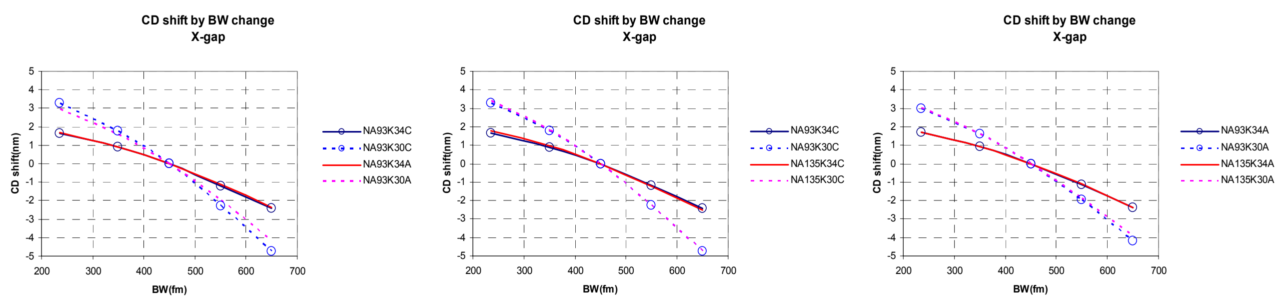

Figure 7. X-gap CD shift due to bandwidth change (E95) for 6F2 cell design. Left graph shows dependence of CDSDPM on illumination condition and k1 at the same NA. Middle and right show dependence on k1 and NA at the same illumination condition.

For a dose correction scenario, the custom illumination case has better tolerance to bandwidth change than the annular illumination case since the CD shift directions between Y-space and X-gap had the same response to bandwidth changes, less than 1.8 CDSDPM for all cases (Figure 8.) As expected, smaller k1 imaging showed larger CD shift due to bandwidth change for both illumination conditions.

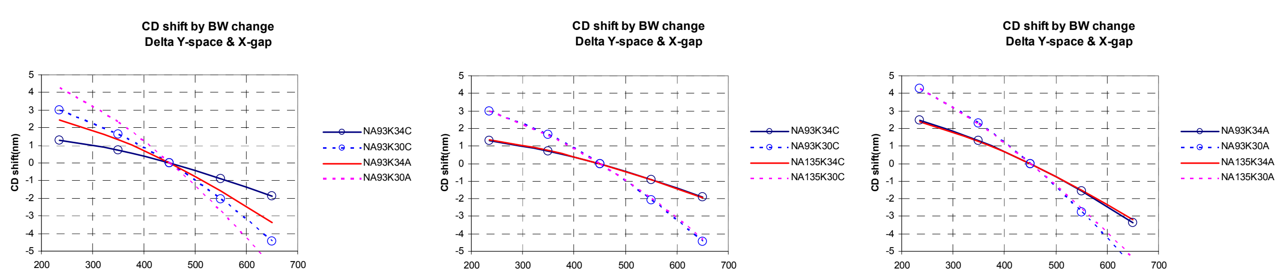

Figure 8. Practical CD delta due to bandwidth change (E95) for 6F2 cell design.Left graph shows dependence of CDSDPM on illumination condition and k1 at the same NA. Middle and right show dependence on k1 and NA at the same illumination condition.

2.3 Dependence on illumination and k1 factor – Gate layer

Since simple dense structures, like cell area layout for the example case, have very high depth of focus, the CD change due to bandwidth change was minimal, less than 1nm for more than 300fm bandwidth range, which is well beyond the normal laser operation range. As expected, SRAF helped to reduce the CD shift of isolated two-line patterns due to bandwidth change since SRAF helped to increase the depth of focus of the patterns, 0.7 versus 1.0 of CDSPPM (Figure 9)[6].

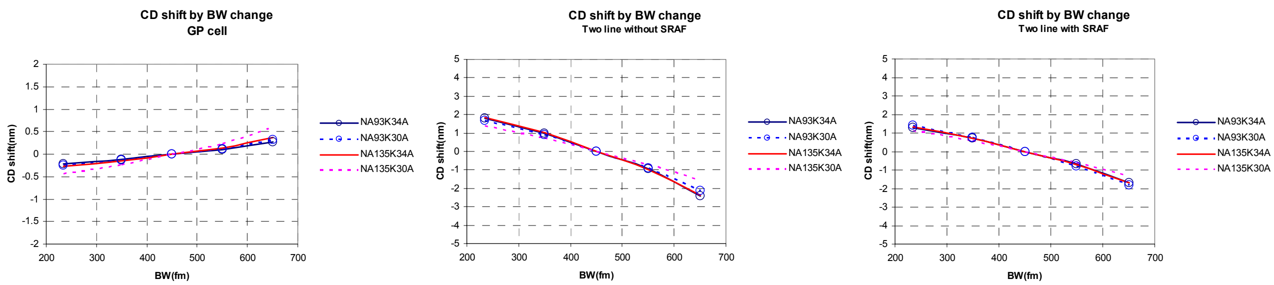

Figure 9. CD shift vs. Bandwidth change (E95) for dense cell (left), isolated two lines (middle) and two lines with SRAF (right)

2.4 CD shift compensation by illumination adjustment

It was found that CDSDPM can be minimized by changing illuminator shape, such as sigma width, sigma center and angles, if other OPE CD changes caused by the illuminator parameters' changes can be tolerated. The annular illumination case for diffusion layout 6F2 design is shown in Figure 10. When bandwidth gets larger, the Y-space CD became larger and the X-gap CD became smaller. By moving sigma center inward , we can move both CDs to the value of CD before the change. We found that CD shifts by bandwidth shift can be minimized by a sigma center move for both 6F2 design and 8F2 design cases (Figure 11). This approach can only be useful for diffusion layer of DRAM, which has tighter CD control requirements within the memory cells than outside of it. However this approach is not as useful for gate layer, which has many transistors with multiple sizes and pitches, all with tight CD control requirements.

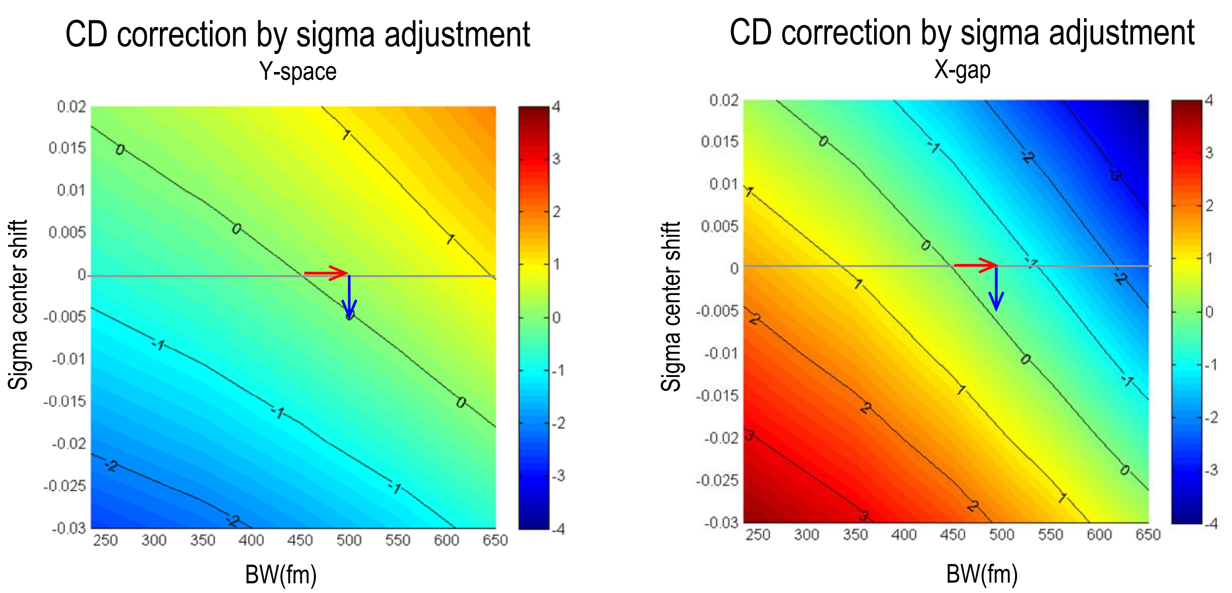

Figure 10. CD response to sigma center & bandwidth change for both Y-space and X-gap (6F2 layout with annular illumination)

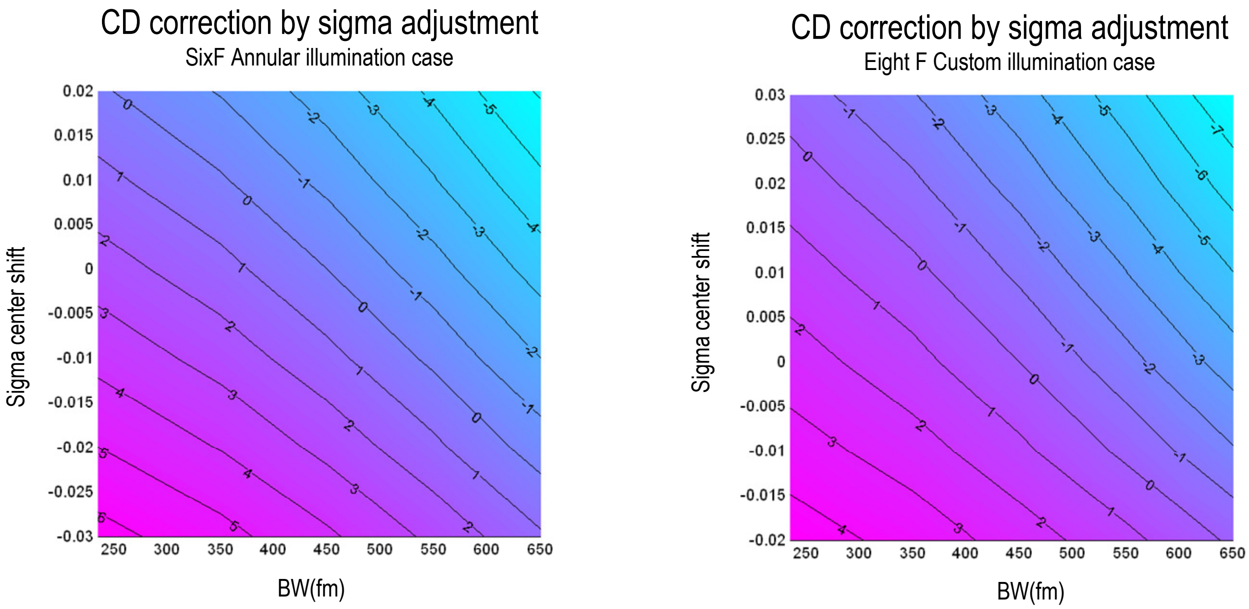

Figure 11. CD correction window by sigma center Both 6F2 layout with annular illumination and 8F2 layout with custom illumination)

3. DISCUSSIONS AND SUMMARY

This simulation study has examined the contribution of variations in laser bandwidth on DRAM CD control. Through various simulations, it was demonstrated that CD shift due to bandwidth change can be minimized by various means

1. finding illumination conditions which have low sensitivity to bandwidth change, like custom illumination case of 6F diffusion layer, or
2. adjusting dose if all critical CDs changes are in the same direction or
3. inducing an opposite CD shift through illumination parameter changes, which requires thorough checks of process impact of other critical patterns.

Although it has been shown that adjusting process conditions to compensate for bandwidth change is possible, it is an undesirable approach since it adds extra complexity to an already constrained process environment. Prevention of bandwidth variation in the laser during laser operation is much more desirable solution. Although passive control of laser bandwidth has improved considerably over the years, Cymer has recently introduced state of the art Active Bandwidth Control (ABS), which can stabilize bandwidth to under +/-50fm range throughout the lifetime of the laser. Based on these simulations, this would control CD shifts to below 1nm for gate layer and 2nm for diffusion layers. ABS is also available with a tunable function (T-ABS) which would allow some degree of process matching between scanners or processes.

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